BBC RD 1973/3

1969
THE QUEEN'S AWARD
TO INDUSTRY

RESEARCH DEPARTMENT

REPORT

RADIO MICROPHONE: propagation characteristics in television studios

R.D.C. Thoday, C.Eng., M.I.E.R.E.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION April 1973 (RA-106)

BBC RD 1973/3
UDC 621.391.81
621.396.65
621.397.712.3

RADIO MICROPHONE: PROPAGATION CHARACTERISTICS IN TELEVISION STUDIOS

R.D.C. Thoday, C.Eng., M.I.E.R.E.

Summary

This report gives the results of an investigation into propagation conditions which exist in television studios for the operation of radio microphones, and indicates the improvement in reception which can be obtained by using a diversity system.

Issued under the authority of

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

(RA-106)

RADIO MICROPHONE: PROPAGATION CHARACTERISTICS IN TELEVISION STUDIOS

Section	Title	Page
	Summary	Title Page
1.	Introduction	1
2.	Propagation of radio frequency waves in studios	1
	2.1. Equipment	1
	2.2. Measurements	1
	2.3. Results of measurements	2
3.	Diversity reception	3
	3.1. Evaluation of results	4
	3.2. Diversity system	4
4.	Modulation	4
5.	Conclusions	4
6.	Reference	5
	Appendix 1	5
	Appendix 2	6
	Appendix 3	6

(RA-106)

April 1973

BBC RD 1973/3
UDC 621.391.81
621.396.65
621.397.712.3

RADIO MICROPHONE: PROPAGATION CHARACTERISTICS IN TELEVISION STUDIOS

R.D.C. Thoday, C.Eng., M.I.E.R.E.

1. Introduction

Radio microphones have been used in BBC studios for a considerable length of time. The Designs Department radio microphone equipment, using frequency modulation and operating with carrier frequencies in Band I has been the equipment most used to date. Experience with this and other radio microphones operating in the u.h.f. and v.h.f. frequency bands has not been entirely successful and consequently their use has not been as widespread as it might have been bearing in mind the freedom which they can impart to producers and performers for certain types of programme material. The principal difficulty lies not with the equipment so much as with the propagation conditions in the studios. It is this aspect of radio microphone operation which is the subject of this report.

2. Propagation of radio frequency waves in studios

The walls, floor and roof of a television studio act as good reflectors at radio frequencies; the reflection is due to the metal grills which retain the sound absorbing material against the walls, the re-enforcement in the concrete flooring, the metal lighting gantries and high level fittings. Radiation from a radio source within an empty studio produces a complex standing wave field made up from the primary wave and multiple reflected wave. The standing wave pattern is, of course, dependent on the studio dimensions, transmitted frequency, and source position. The addition of metal objects such as cameras, scenery and lights affect the field pattern and the polarisation of signals is not preserved.

It is impossible to predict the field pattern even for an empty studio because its irregular shape combined with the clutter caused by the fixtures results in a very complex situation. The field pattern can, therefore, be ascertained only by measurement.

2.1. Equipment

The propagation measurements were made in Studios 3 and 8 at Television Centre. Hand-held test transmitters were carried over the studio floor in a regular pattern while field strengths picked up by two separate receiving aerials were continuously recorded. Measurements were made with source frequencies in Bands I, II, III, IV and V. Vertical polarisation was used in all the tests as this was considered to be the most likely polarisation of the transmitted signal in the studio environment. The Band I and II transmitter equipment comprised fixed frequency transistor oscillators producing output powers of up to 100 mW. The Band II transmitter was used in conjunction with a varactor diode frequency doubler to produce the Band III signal.

The u.h.f. sources employed crystal controlled oscillators, having fundamental frequencies of 65·25 and 94·5 MHz, followed by step recovery diode multipliers to give output carrier frequencies of 522 and 756 MHz respectively. The transmitting aerial used for the Band I, II and III tests consisted of a 0·8 m long centre-fed element (approximately a half-wave length at Band III), driven from a balun transformer and inter-changeable matching networks. The u.h.f. transmitting aerials were $\lambda/2$ dipoles fed from baluns. All receiving dipoles were vertically polarised; the elements were made a half wavelength long at the test frequency with their output terminals connected to a suitable balun. Two receiving aerials, positioned at separate locations, were used for each test, the signals from them being measured and recorded using field strength measuring receivers and a twin track pen recorder. The receivers employed logarithmic I.F. stages and provided outputs proportional to the logarithm of the input r.f. signal levels. The pen recordings were, therefore, directly calibrated in decibels. The arrangement is shown in Fig. 1.

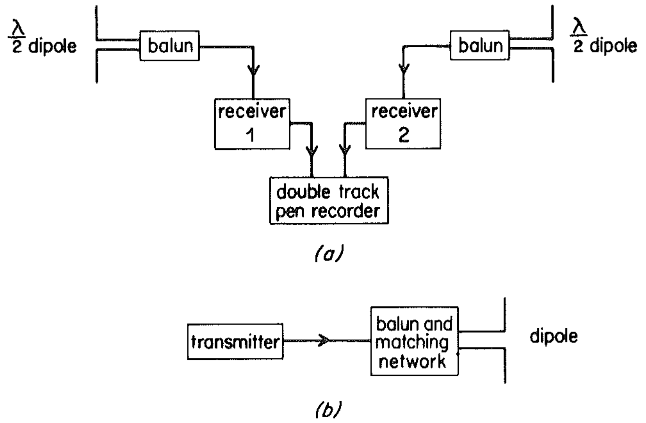


Fig. 1 - General arrangement of equipment
(*a*) Fixed receiving equipment
(*b*) Portable transmitter and dipole aerial

2.2. Measurements

As stated in Section 2.1 measurements were made by carrying the transmitter across the studio floor in a regular pattern. The transmitting dipole was held, with the element vertical, at arms length from the body. The dipole was deliberately kept away from the body so that the aerial

(RA-106)

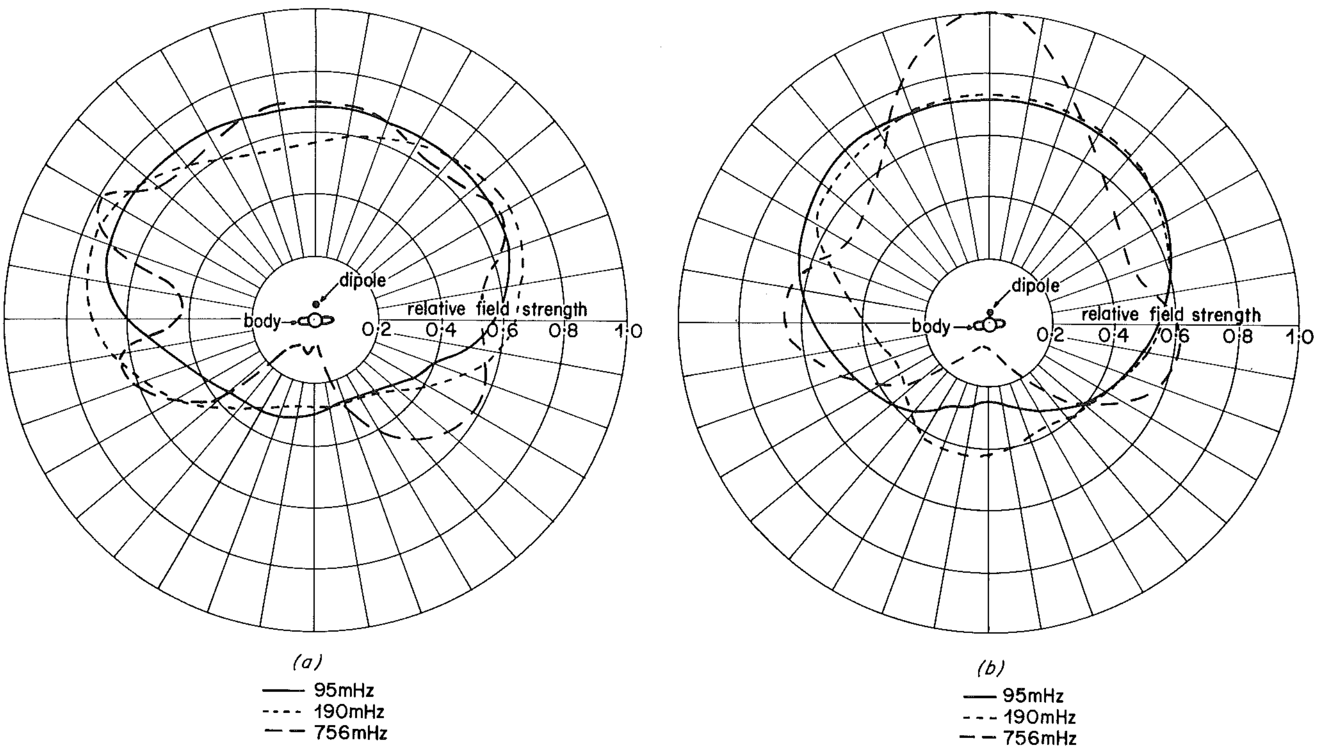


Fig. 2 - Horizontal radiation patterns of transmitting aerial
(*a*) dipole held at arms length (*b*) dipole held close to the chest

impedance was reasonably well preserved. The horizontal radiation patterns (h.r.p.) of the dipole and body combination at various frequencies are shown in Fig. 2(*a*). This arrangement simulates the position for the hand-held integrated radio microphone which is usually of cylindrical form, the batteries and transmitter being contained within, the case acting as the radiating element. As a comparison the radiation pattern with the radiating element close to the users chest are shown in Fig. 2(*b*). Figs. 2(*a*) and 2(*b*) show small differences between corresponding h.r.p.'s at v.h.f. but considerable difference at u.h.f. The results of tests at v.h.f. should be fairly representative of most types of radio microphone aerial; the results at u.h.f. will apply more to the integrated type of radio microphone but should still give an indication of the results which will be obtained with a lanyard aerial.

2.3. Results of measurements

Four main tests were carried out in studios at the Television Centre, details of which can be found in Appendix 1. Typical pen traces obtained from the

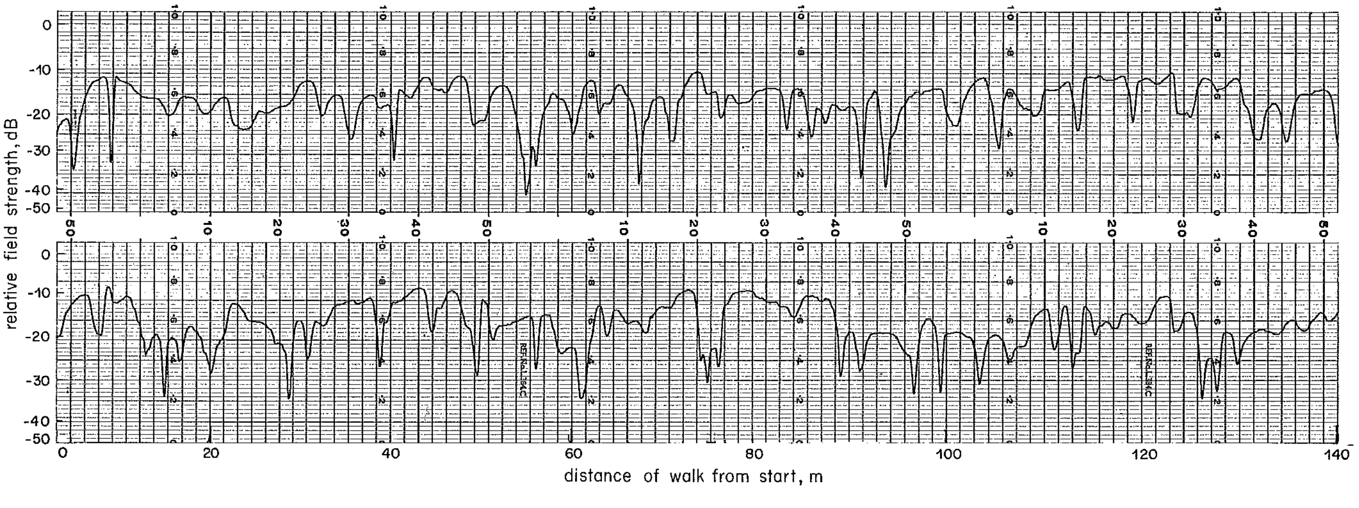


Fig. 3 - Record of received signals from two aerials on 51·3 MHz as test transmitter was carried backwards and forwards across studio floor

recorded receiver outputs are shown in Fig. 3. The deeper minima occur at approximately half wavelength intervals and increase in number approximately proportionally with frequency. The largest maximum to minimum ratio measured was, for most tests, in excess of 40 dB. These ratios, shown in Table 1 of Appendix 2, are not necessarily the maximum ratios which existed in parts of the studio.

The results obtained from one of the receiver outputs in tests at 51·3 MHz were analysed and plotted on arithmetic probability paper shown in Fig. 4. The straight line character shows that the distribution of fields is approximately log-normal; it is therefore appropriate to express the field strength in decibels relative to a mean value.

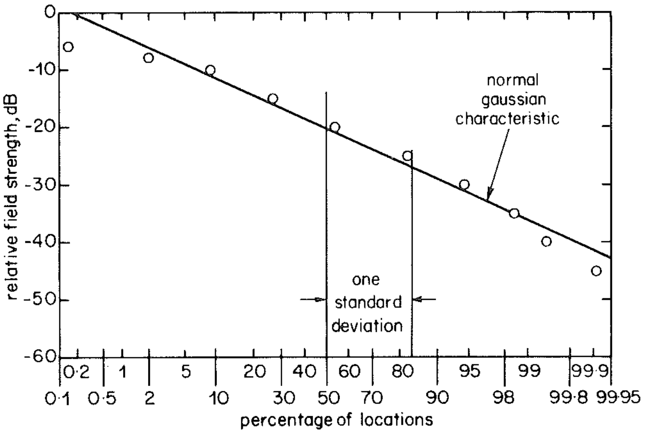


Fig. 4 - Distribution of field strength with locations (Receiver (a) 51·3 MHz, test 2)

The general analysis of charts was carried out to provide approximately 500 pairs of measurements for each complete coverage of the studio floor. In some cases an increase in the number of samples was made but analysis showed very small differences from the results obtained with 500 samples.

The standard deviation (σ) for all tests lay within the range 5 to 8 dB. In some cases the standard deviation of the simultaneous recordings differed in value by up to 1·8 dB (see Table 2 Appendix 2). These differences were probably due to reflections from various studio fixtures in fairly close proximity to the receiving aerials.

The results have shown that with a transmitter power of 10 mW the mean receiver input voltages were approximately 1 mV for measurements taken in Studio 8 and 2 mV for those in the smaller Studio 3. These figures include an allowance for feeder loss and assume that the transmitting and receiving aerials are reasonably well matched. In practice, to allow for feeder losses and aerial inefficiences, the transmitter power would need to be increased to between 25 and 50 mW to obtain the same mean field strength. A receiver input of about 160 μV is the minimum that will guarantee Grade 1 reception. Therefore signal reduction of more than 16 dB below the mean will result in a degraded microphone circuit.

3. Diversity reception

Two spaced, half-wave, vertical dipoles with separate receivers and recording channels were used in the propagation tests and it is possible to use the results to assess the advantage of a dual-channel diversity system directly by calculating the correlation coefficient ρ between corresponding data samples in each test and then determining (from the Gaussian bivariate density function) the percentage of transmitter locations which will give signal levels equal to or less than chosen deviations from the mean signal level.

In mathematical terms the correlation coefficient ρ can take any value in the range +1 to −1. In practical situations associated with radiation problems, ρ can have positive or slightly negative values. It is desirable in the case of dual-channel diversity for it to be as negative as possible.

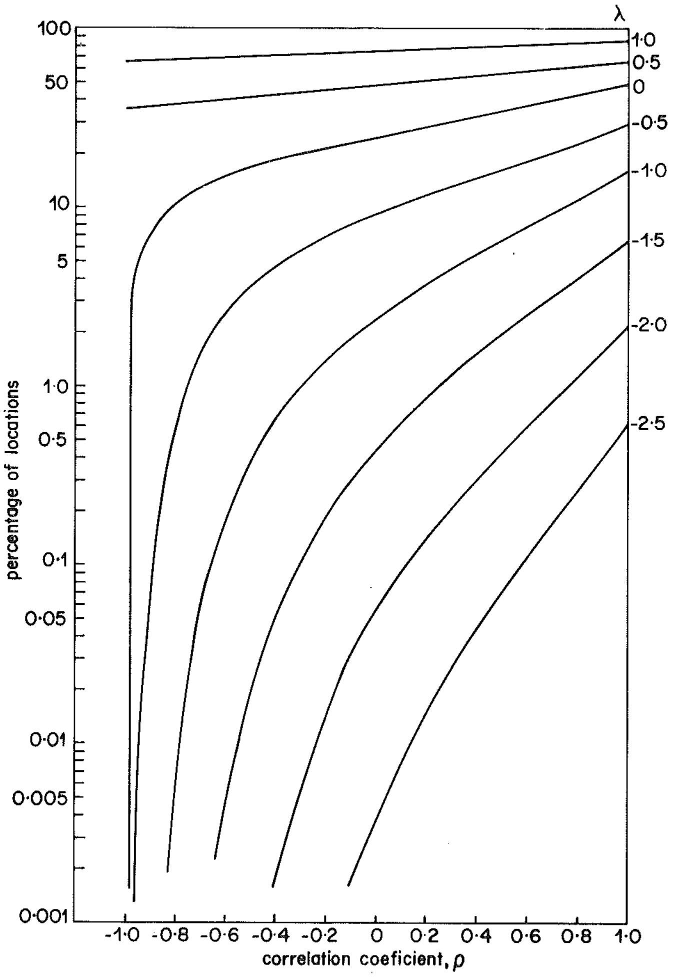


Fig. 5 - Percentage of locations at which the received signal at one aerial of two will exceed $\lambda\sigma$ dB relative to the mean (overall locations) as a function of the correlation coefficient ρ. (Based on the bivariate gaussian distribution)

Fig. 5 is derived from tables[1] of the bivariate probability density function and shows the effect ρ has on the number of locations in which the field strength will be equal or less than a given deviation from the mean value. The variates are assumed to have equal standard deviations.

It should be noted that when $\rho = +1$ the two variates are dependent and the distribution probability becomes the same as for a single variate.

3.1. Evaluation of results

From data provided by the measurements, the calculated correlation coefficients were negative in value for all tests except for Test 1. The difference between the conditions for this and other tests was in the positioning of the receiving aerials which were not widely spaced and were, therefore, situated in the same region of the studio. For the tests using widely spaced receiving aerials the value of ρ ranged from —·07 to —·26 (see Table 3, Appendix 2). The variation in ρ was scattered throughout the frequency bands and it can be inferred that no particular band of frequencies is better than another in the studio environment.

It is shown in Appendix 3, that for the worst-case occurring in the measurements, other than those obtained for Test 1, the percentage of transmitter locations for which sub-standard reception is likely to occur is reduced from 2% for the single channel to ·03% using dual-channel diversity reception.

The results indicate that by using widely spaced receiving aerials in the studios it should be possible to obtain values of ρ which are never greater than zero so that the probability of a poor result will never be greater than the square of the signal channel probability.

3.2. Diversity system

In the foregoing, it is shown that reception conditions can be considerably improved by using dual-channel selection diversity. However, a diversity system need not be limited to two channels and a further improvement in performance can be achieved by using multichannel diversity. In fully equipped studios where there is a likelihood that one or more receiving aerials will be obscured by scenery etc., a minimum of four channels is recommended.

Amongst the possibilities for a diversity system, selection diversity has the advantage of simplicity but does in effect require as many receivers as channels whether the selection is performed at r.f. or a.f. The output signal is subject to transitional noise when switching from one channel to the other and the signal-to-noise ratio is never better than that of the best channel.

A diversity system employing pre-detection combining in which the r.f. signals from various reception points are brought into a co-phased condition before combination, gives a larger signal level than that obtained from selection diversity but the circuitry required is complex, although only one receiver channel is necessary. It suffers from a practical difficulty in that the phase adjustment cannot be made to track continuously and may produce zero signal at the receiver input temporarily, even though the received signals are high.

Frequency diversity has not been considered because of the complication of providing a second channel in the transmitter.

A system in which the outputs from several identical receivers are combined to give optimal advantage in signal-to-noise by employing the weighted addition of the audio outputs has been tried experimentally in the laboratory and appears to work.

It is appreciated that an ideal system would employ at least four receiving aerials, suitably disposed in the studio, feeding four receivers whose audio outputs are combined with optimal weighting. Such a system would be expected to give satisfactory results under all conditions of studio usage and, if properly engineered, would require no adjustment or setting up. Thus, it would provide a permanent audio input to the sound desk having equivalent status to other microphone inputs. The complexity inherent in the weighted combination of four circuits can probably best be achieved by employing digital techniques. This possibility will be examined for feasibility as the next stage of the work.

4. Modulation

The measurements in this report have been concerned with r.f. field distribution only and in no way indicate which system of modulation is optimal for radio microphones. The main criterion is for a modulation system which gives low distortion and good signal-to-noise ratio under normal operating conditions. Frequency modulation meets this requirement without undue complication. It is used in available equipment and no immediate advantage can be envisaged in changing to other forms of modulation.

The maximum deviation employed for v.h.f. broadcasting is ±75 MHz, which is also used in the Designs Department radio microphone. To some extent, a reduction in maximum deviation might give a reduction in signal distortion in low signal strength areas of the studio, but analysis of the problem is difficult. It is thought that the improvement would be marginal and would certainly be at the expense of signal-to-noise ratio in areas of good reception. The use of a diversity system should largely overcome this as well as the more acute problem of signal drop out.

Most radio-microphone transmitters employ limiters to prevent over-modulation but compression of audio signals is not generally used.

5. Conclusions

The measurements of field strength and analysis show similar results for all frequencies and no particular trend can be judged from them. It should be noted that an increase in frequency produces an increase in the number of maxima and minima over the studio area while at lower frequencies each minima covers a larger area than those at higher frequencies but these facts in themselves does not necessarily confer any advantage or disadvantage on any band of frequencies. The choice of equipment does not, therefore, depend critically on the frequency band in which it operates and should be made on the basis of best design and convenience in use.

The analysis has shown that considerable benefit will result from using some form of diversity reception and a quadruple diversity system is being considered as a permanent studio installation.

The transmitter output power should be within the range 25 to 50 mW, even when a diversity system is used, so that the probability of signal drop-out is reduced to a negligible value.

6. Reference

1. PEARSON, V. 1931. Tables for staticians and Biometricians Parts I and II. Cambridge, University Press, 1931.

Appendix 1

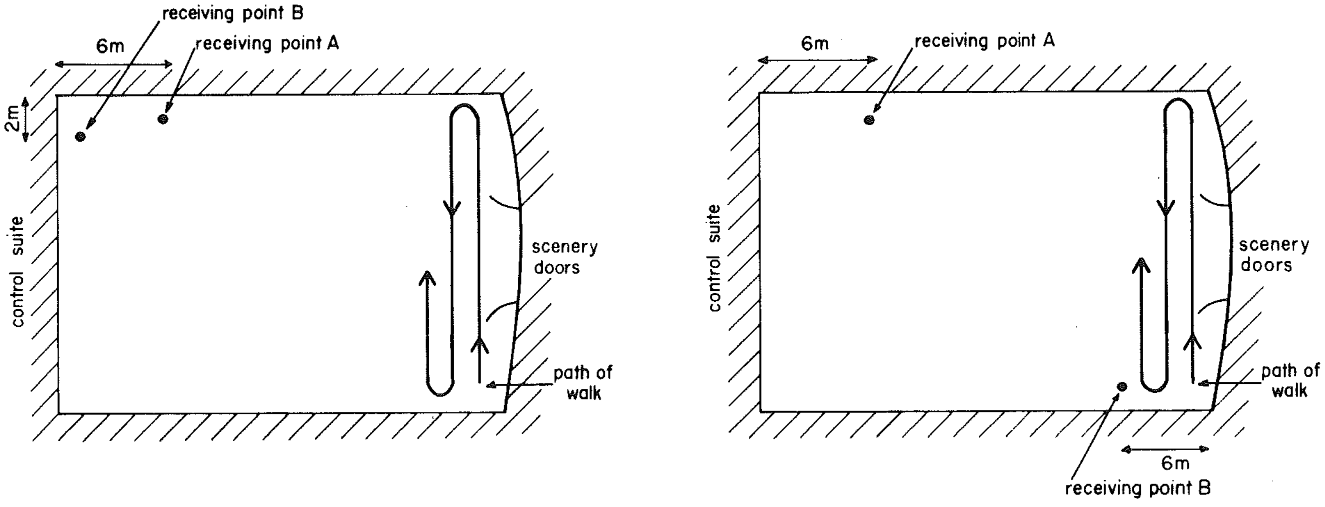
Propagation Tests in Television Studios

Test 1. Measurements were made in Studio 3 at 51·3 MHz (Band I) and 95·3 MHz (Band II) with the receiving aerials in the positions shown in Fig. 6(*a*), 4 m above floor level. The spacing between the dipole and studio wall was 1 m (approximately $\lambda/8$ at Band I and $\lambda/4$ at Band II). The studio was empty and the lights were in the raised position.

Test 2. Conditions were the same as for Test 1 but the receiving aerials were in the positions shown in Fig. 6(*b*).

Test 3. Measurements were made in Studio 8 at 51·3, 95·3 and 190·6 MHz (Band III), with the receiving aerials in positions approximately as shown in Fig. 6(*b*), also at a height of 4 m above floor level. The dipole to wall spacing was the same as for Tests 1 and 2. The studio contained some metalised props from the 'Top of the Pops' set; the lights were in the raised position.

Test 4. The u.h.f. tests were made in Studio 3 at frequencies of 522 MHz (Band IV) and 756 MHz (Band V). The receiving aerials were positioned as shown in Fig. 6(*b*), 3 m above floor level and spaced approximately $0{\cdot}3\lambda$ from the studio walls. The studio was empty except that several sets of lights near the control-suite end of the studio were at floor level.



(*a*) (*b*)

Fig. 6 - Arrangement of receiving aerials in the television studios

Appendix 2

Tables of Results

TABLE 1

Largest Max/Min Ratio Measured in Each Test, dB

Frequency MHz	51·3	95·3	190·6	522	756
Test 1	40	38			
Test 2	41	44			
Test 3	38	43	47		
Test 4				45	44

TABLE 2

Standard Deviation of Each Channel

Frequency MHz	Receiver	51·3	95·3	190·6	522	756
S.D. dB Test 1	(a)	6·1	7·9			
	(b)	7·7	6·1			
S.D. dB Test 2	(a)	6·6	7·6			
	(b)	6·6	6·5			
S.D. dB Test 3	(a)	5·9	7·3	6·8		
	(b)	6·0	7·8	7·2		
S.D. dB Test 4	(a)				5·8	6·8
	(b)				5·8	5·2

TABLE 3

Correlation Coefficient Calculated from Measurements

Frequency MHz	51·3	95·3	190·6	522	756
Correlation Coeff. ρ Test 1	+·32	+·21			
Test 2	−·11	−·07			
Test 3	−·23	−·21	−·10		
Test 4				−·26	−·09

Appendix 3

To assess the improvement gained in using dual channel selection diversity, the minimum input e.m.f. to the radio microphone receiver for grade 1 reception will be taken as 160 μV. This corresponds to 2·1 standard deviations below a mean signal level of 1 mW for the worst case (Band II) for widely spaced receiving aerials where the value of $\rho = -0{\cdot}07$. Reference to Fig. 5 shows that for a single channel ($\rho = +1$) the percentage of transmitter locations for which the receiver input voltage is sub-standard is approximately 2%. In the case of dual selection diversity ($\rho = -{\cdot}07$), this is reduced to ·03%, giving an improvement of 67 times. The same percentage could be achieved for the single channel by increasing the transmitter power approximately 11 dB. Apart from the disadvantage of generating the higher transmitter power, the receiver would be required to operate over a larger range of input voltages.

SMW/JFS

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey